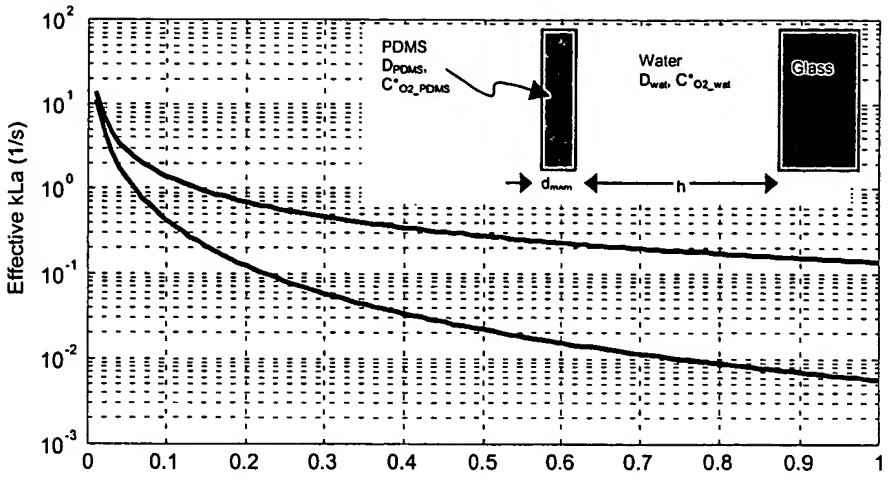
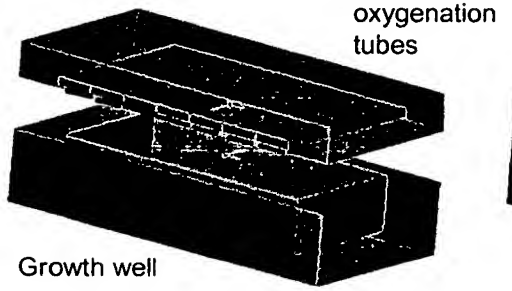

Effective kLa (1/s)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
PDMS
D_{PDMS},
$C^*_{O2\_PDMS}$
Water
D_{wat}, $C^*_{O2\_wat}$
Glass
d_{mem}
h

Figure 1

FIGURE 2

2B Exploded view



2A

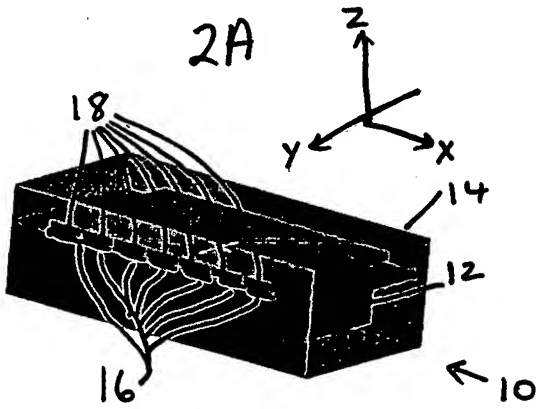
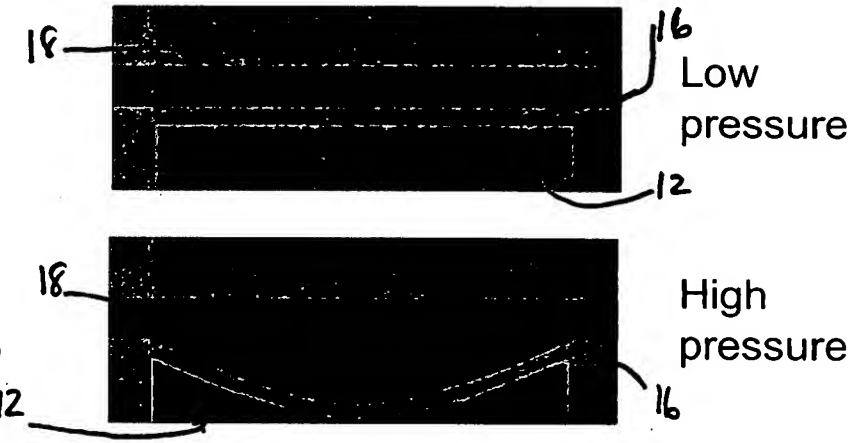


FIGURE 3

Tube profile (cross section view)



Actuation pattern (cross section view)

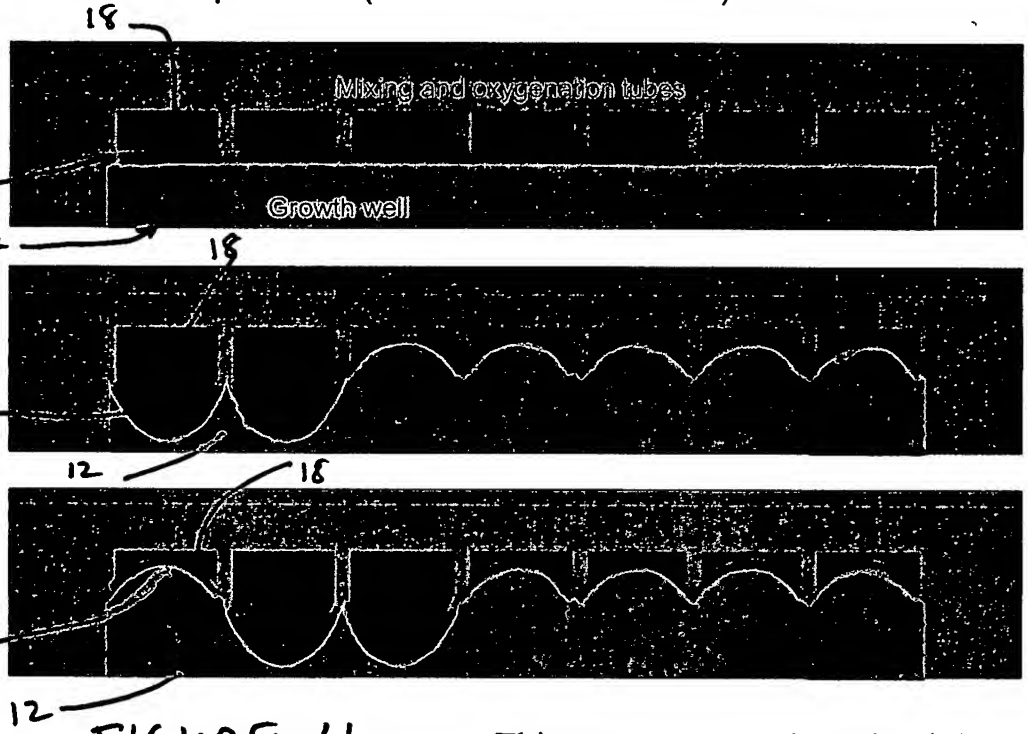
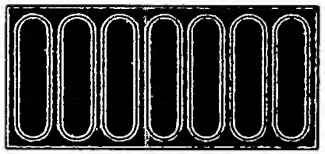


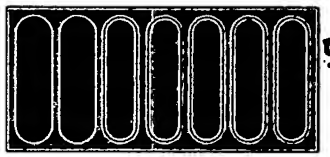
FIGURE 4

This pattern proceeds to the right and wraps around to the left when it reaches the right edge. The next slide shows the entire pattern.

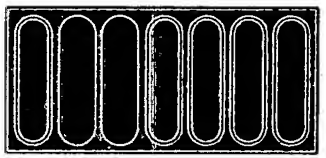
Top views (dark blue indicates pressurization), arrows indicate fluid flow



5A All tubes un-pressurized



5B Two left tubes pressurized, fluid is displaced to the right and up into the un-pressurized tubes.



5C Second tube stays pressurized, first tube is de-pressurized and third tube is pressurized. Fluid is pushed to the right by third tube and around second tube to push up first tube.

FIGURE 5

Approximate flow for straight tubes

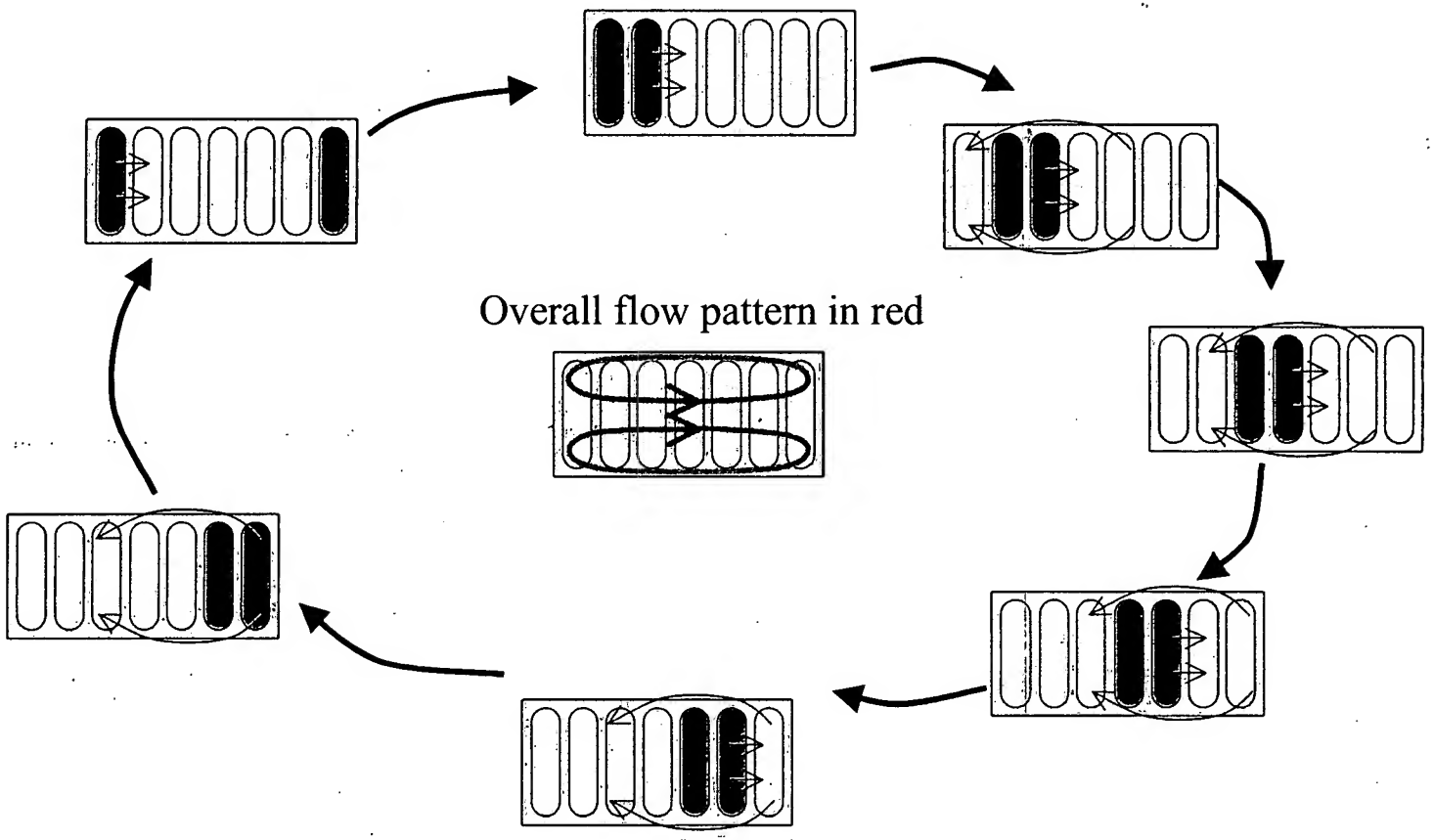
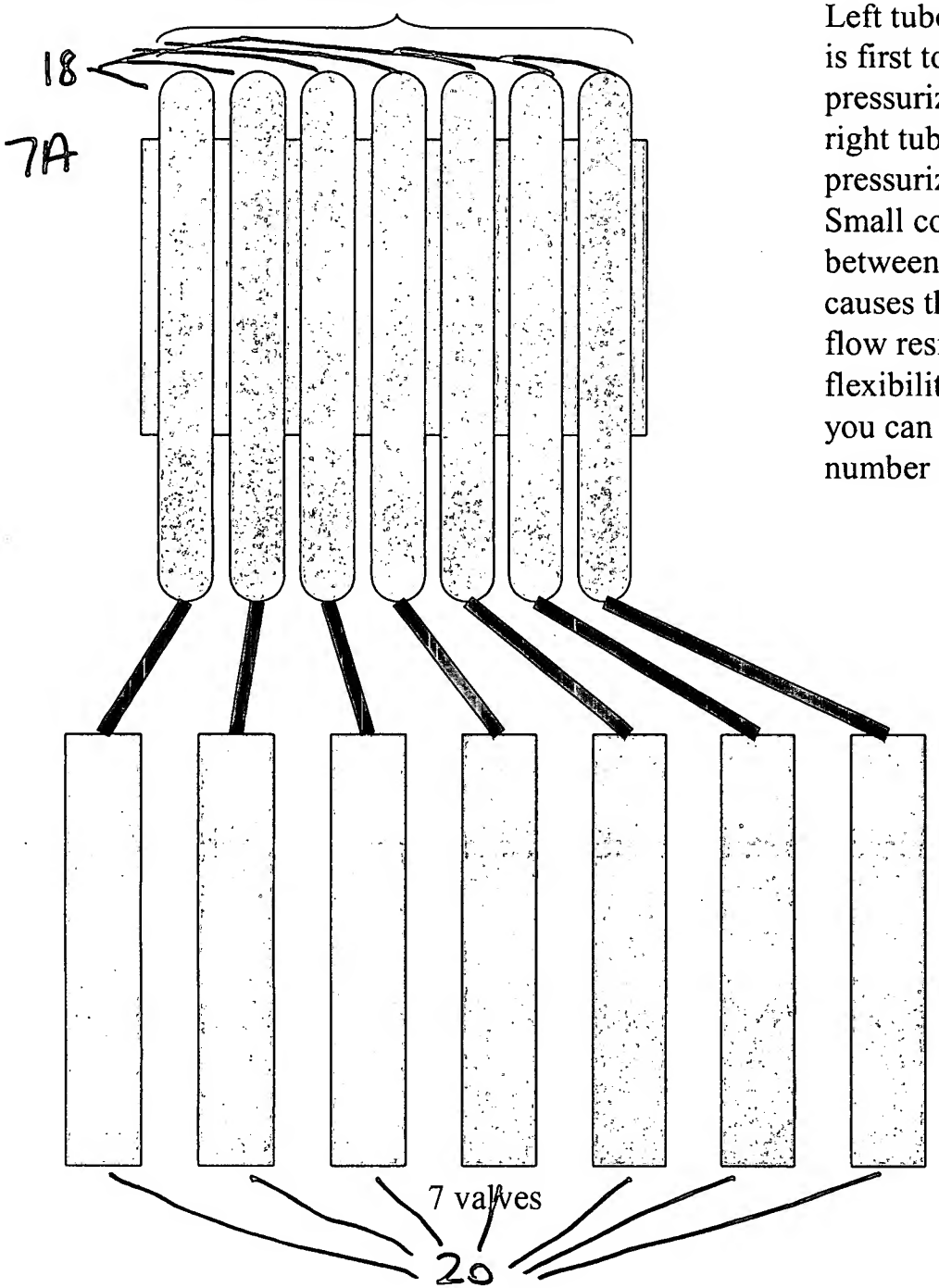


FIGURE 6

FIGURE 7

7 tubes and 7 valves, each tube individually controllable



Left tube in each group is first to pressurize/depressurize, right tube last to pressurize/depressurize. Small connection between left/right tubes causes the delay (high flow resistance) Some flexibility is lost, but you can reduce the number of actuators.

7 tubes and 3 valves, each color group is controllable.

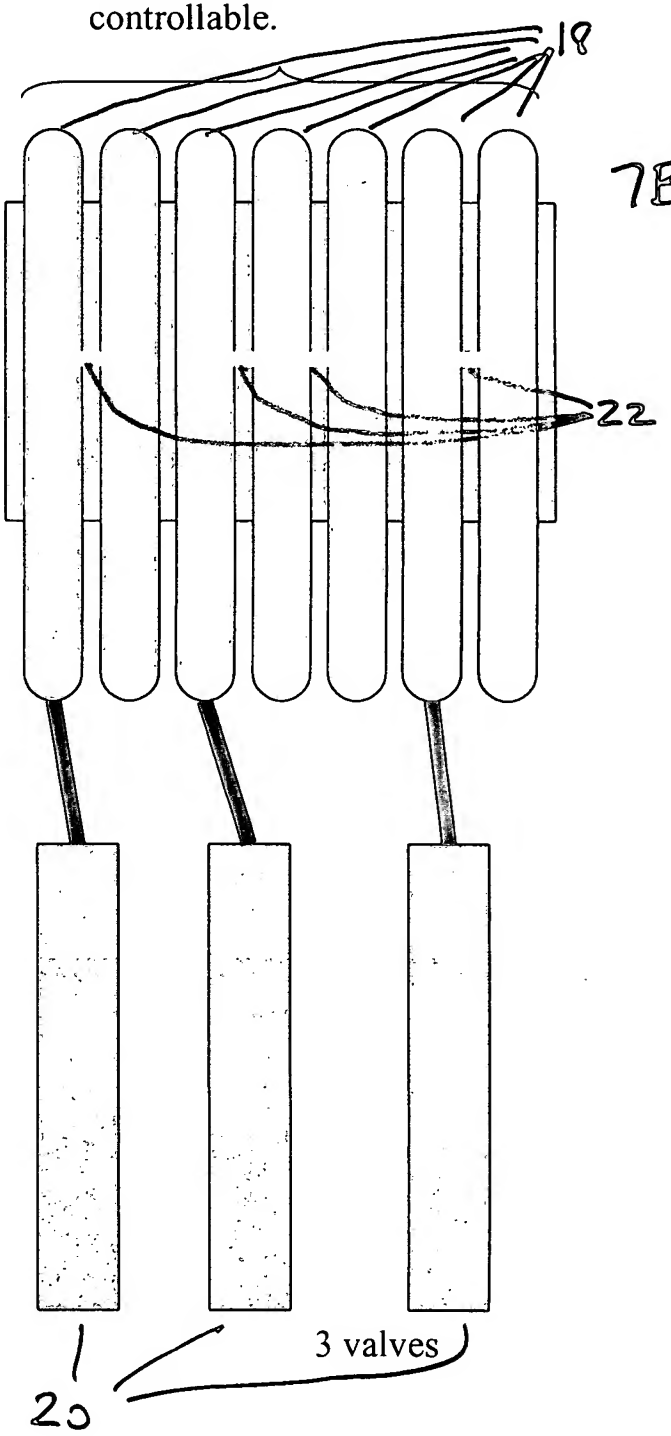
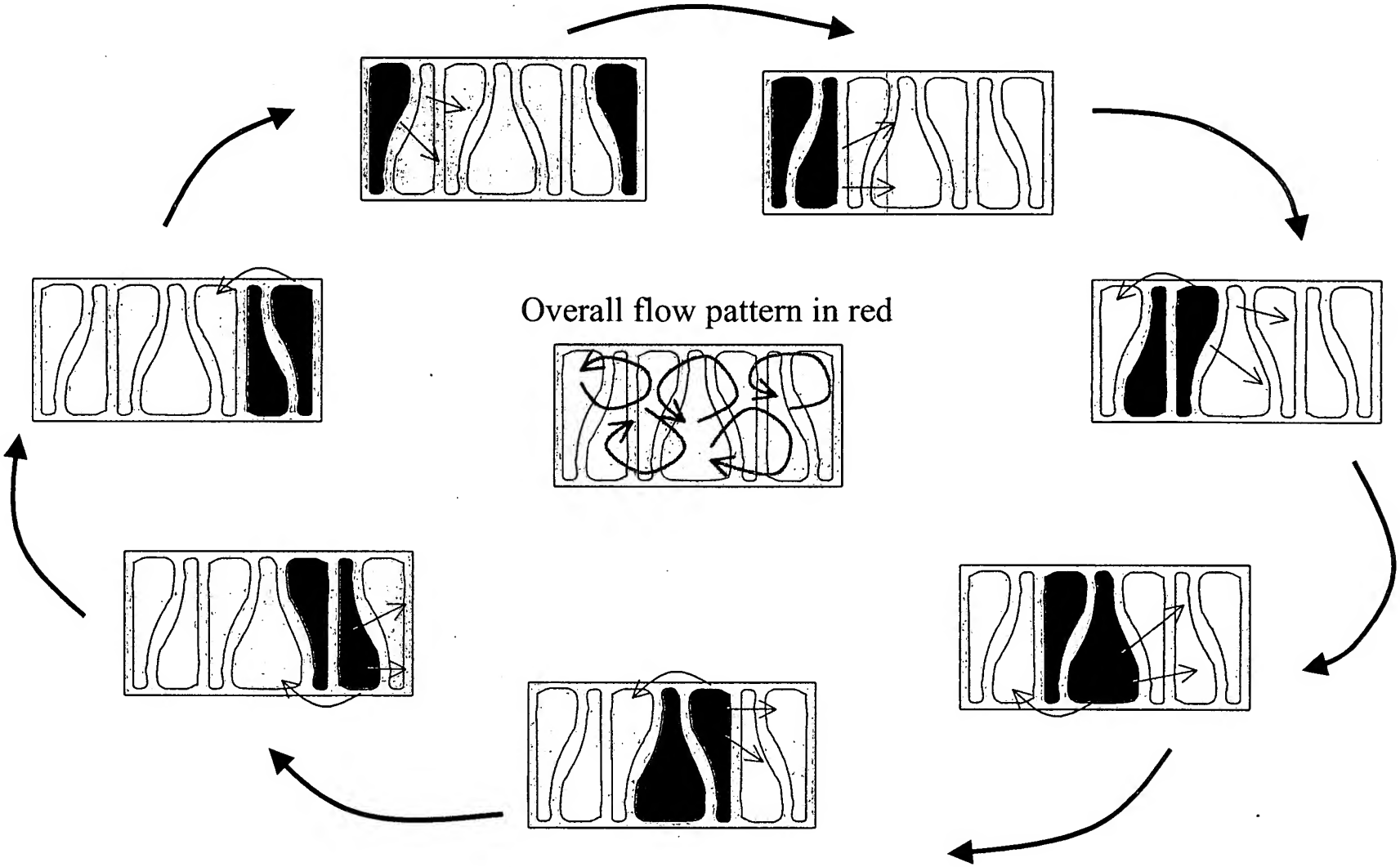


FIGURE 8

Approximate flow for wiggle (variable width tubes)



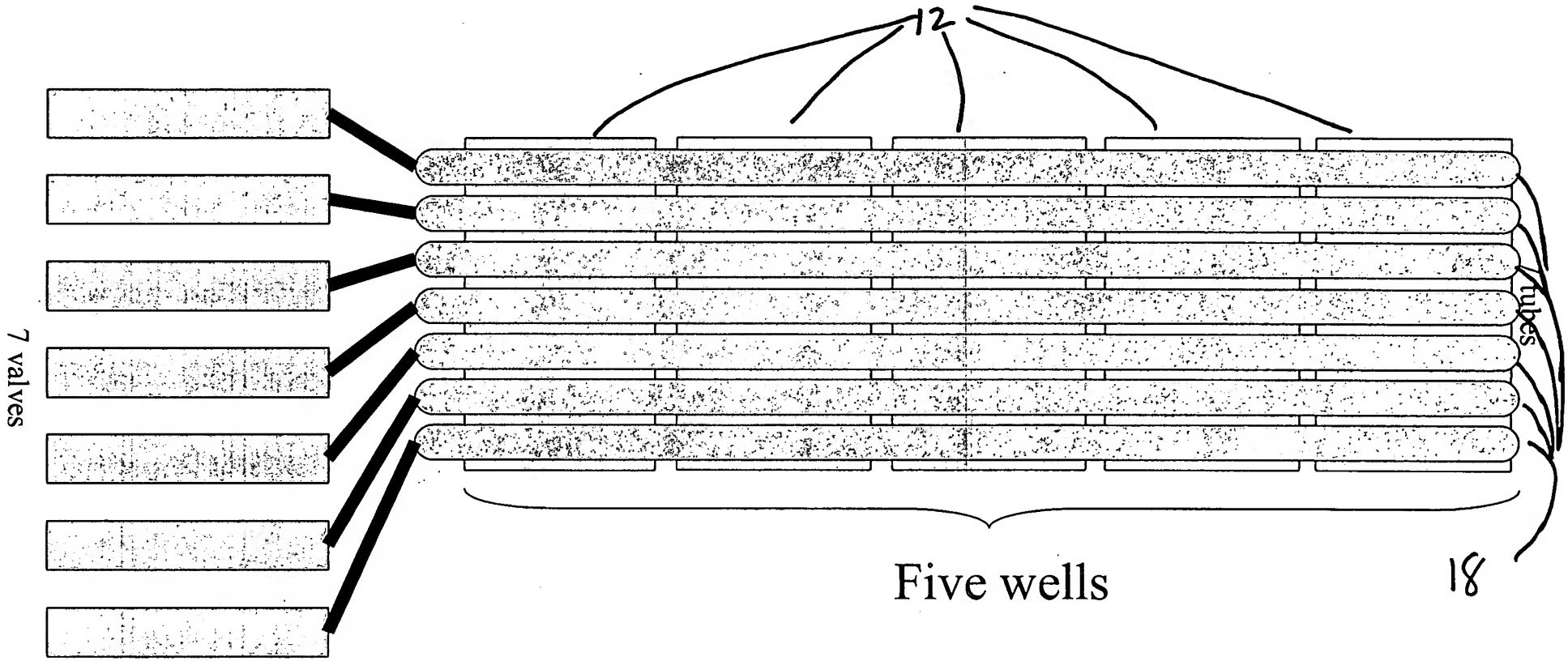


FIGURE 9A

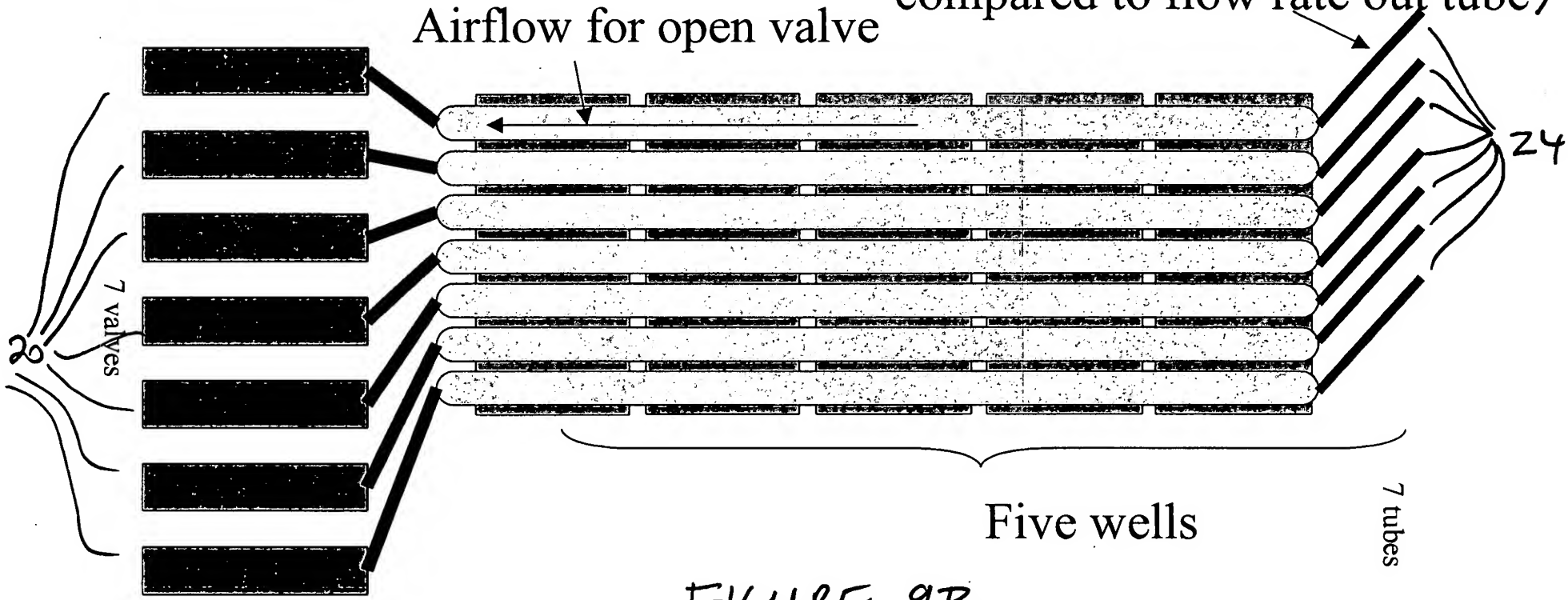


FIGURE 9B

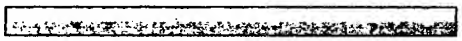
7 individual valves open means air flows and tube is not pressurized. Closed means tube is pressurized to whatever the individual high pressure line pressure is.

Fabrication process

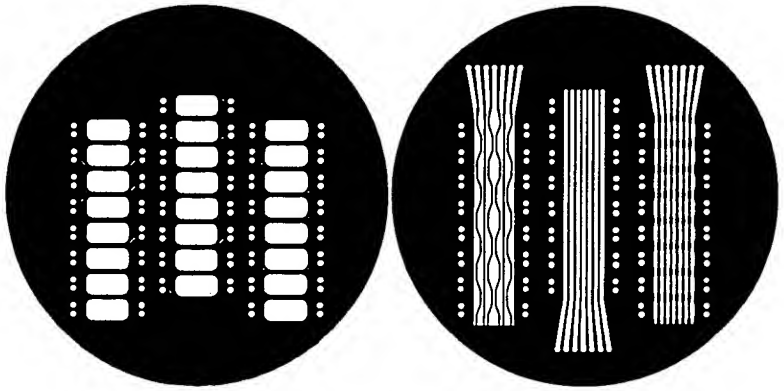
FIGURE 10

A

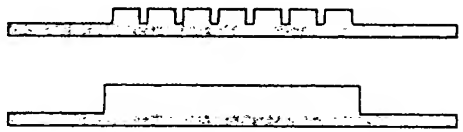
Make mold: SU-8 photolithography



Spin on SU-8, pre-bake



Expose with transparency mask

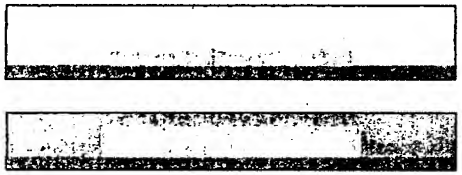


Post-exposure bake, develop, silanize

Elastomer casting

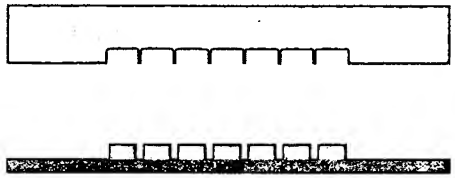
B

50min 65ºC 8:1



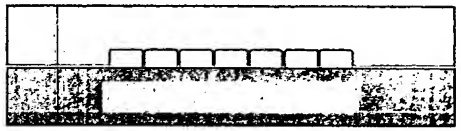
20min 65ºC 20:1

C



Peel and punch holes to access tubes

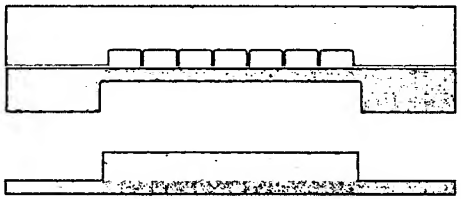
D



Align and seal

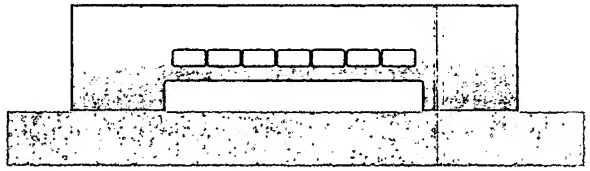
Full Cure 2 hrs 65ºC

E



Cut out individual devices and peel from mold

F

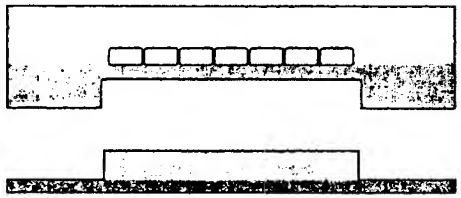


Seal to microscope slide

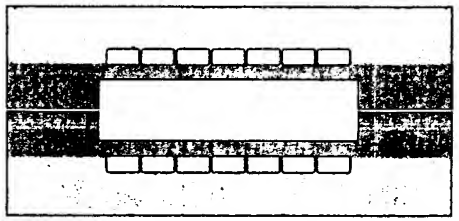
Bake ~2 hrs 65ºC

FIGURE 11

Another variation:



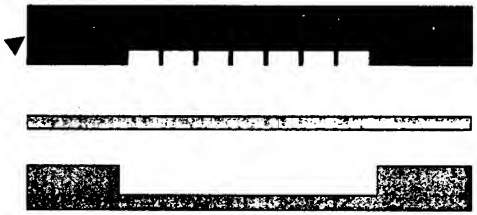
Cut out individual devices and peel from mold



Seal two together back to back for double sized chamber.

Another embodiment

Same elastomer molded tubes, or etched glass tubes, or laser machined tubes in plastic

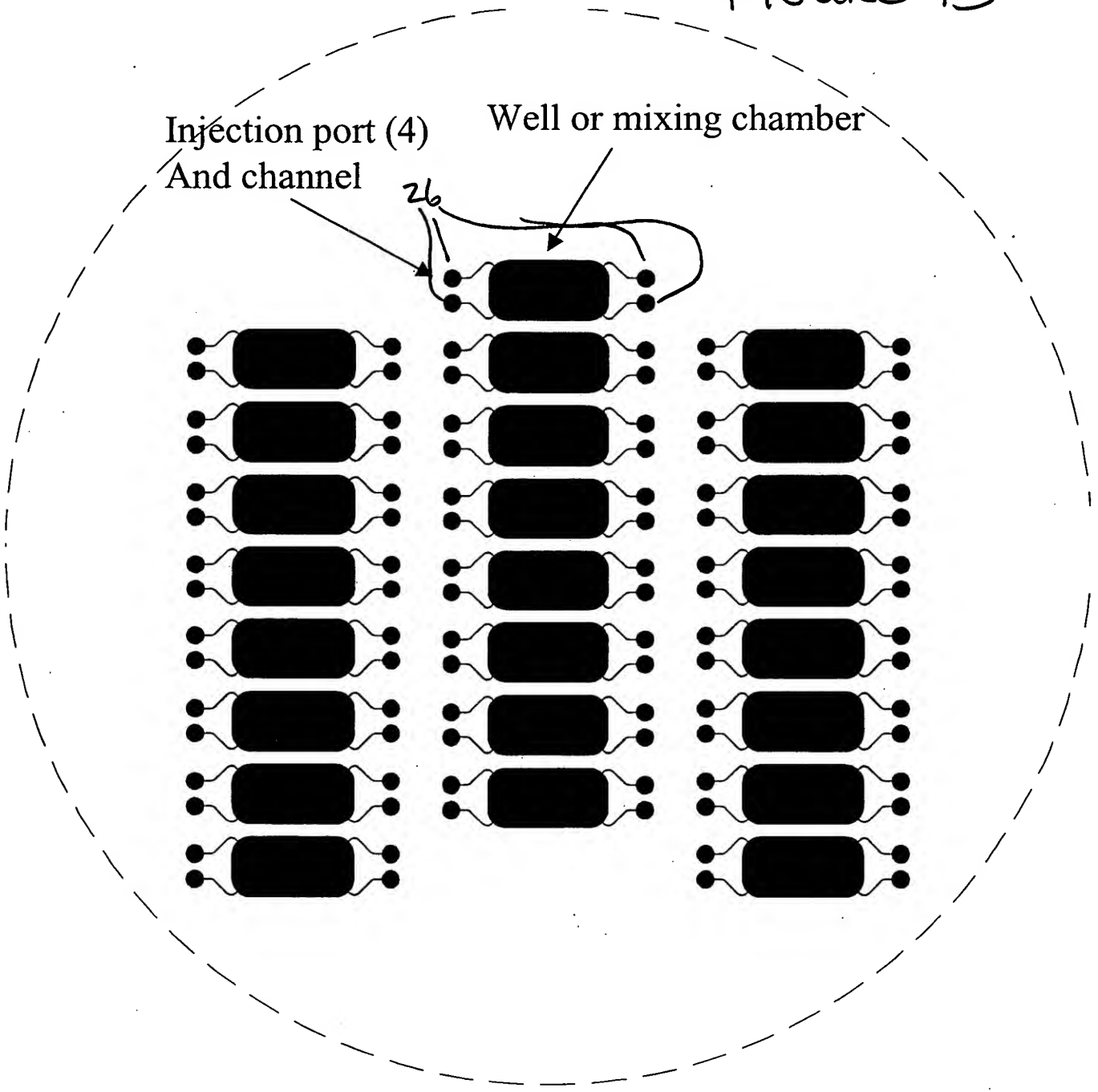


Conventionally machined wells, or injection molded wells, or epoxy molded wells, or elatomer molded wells.

Thin 100-300um thick PDMS membrane spin on and peel off

FIGURE 12

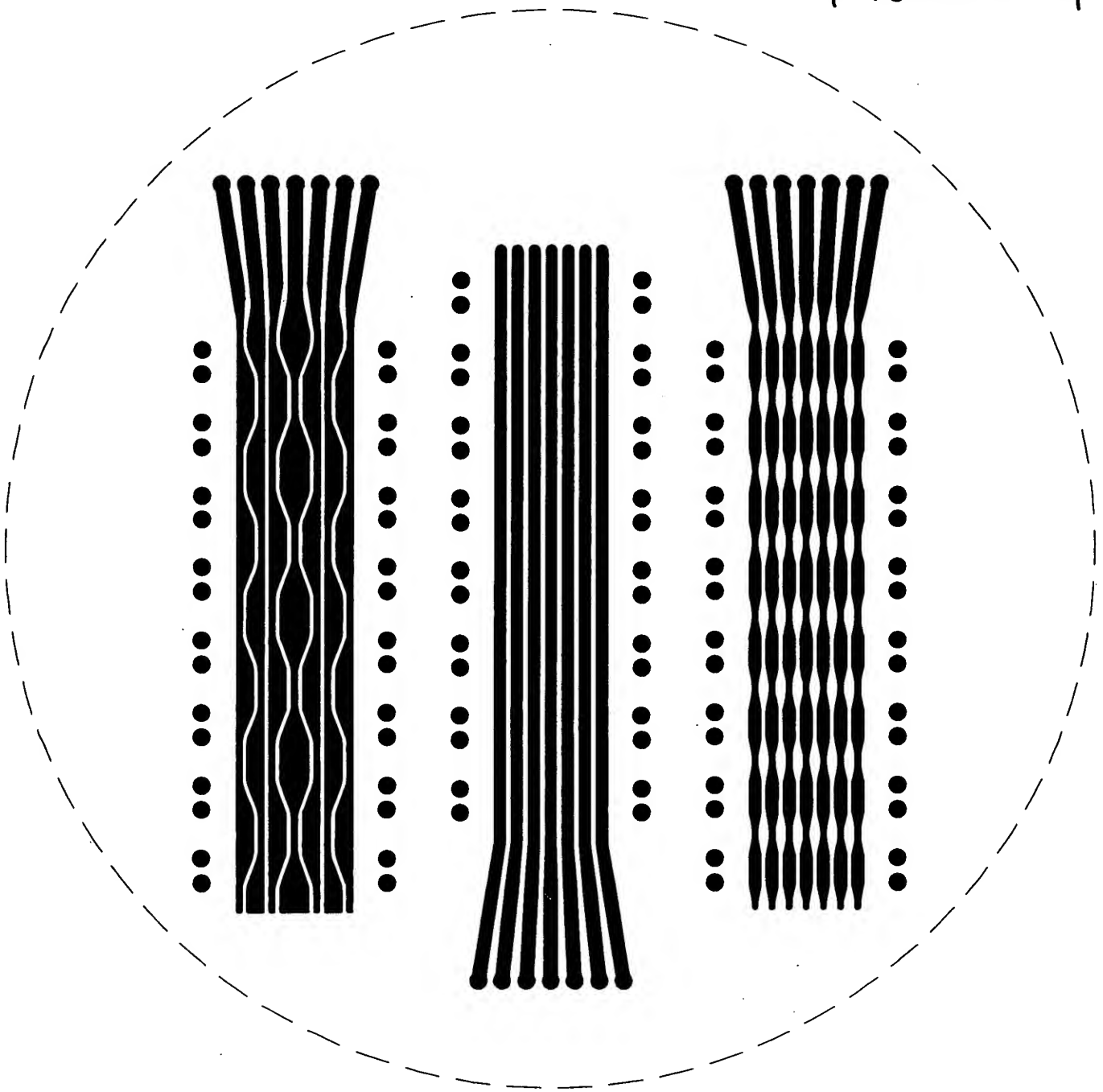
FIGURE 13



This is the mask for the well, or chamber mold. The dashed circle is 3.5 inches in diameter and each well is 5mm x 10mm. The spacing between the wells is 1mm.

The dark areas on the mask will result in raised structures (typ: 300-500μm) on a silicon wafer substrate to form the mold. After casting the elastomer and peeling it off, the dark areas will be cavities in the silicone elastomer.

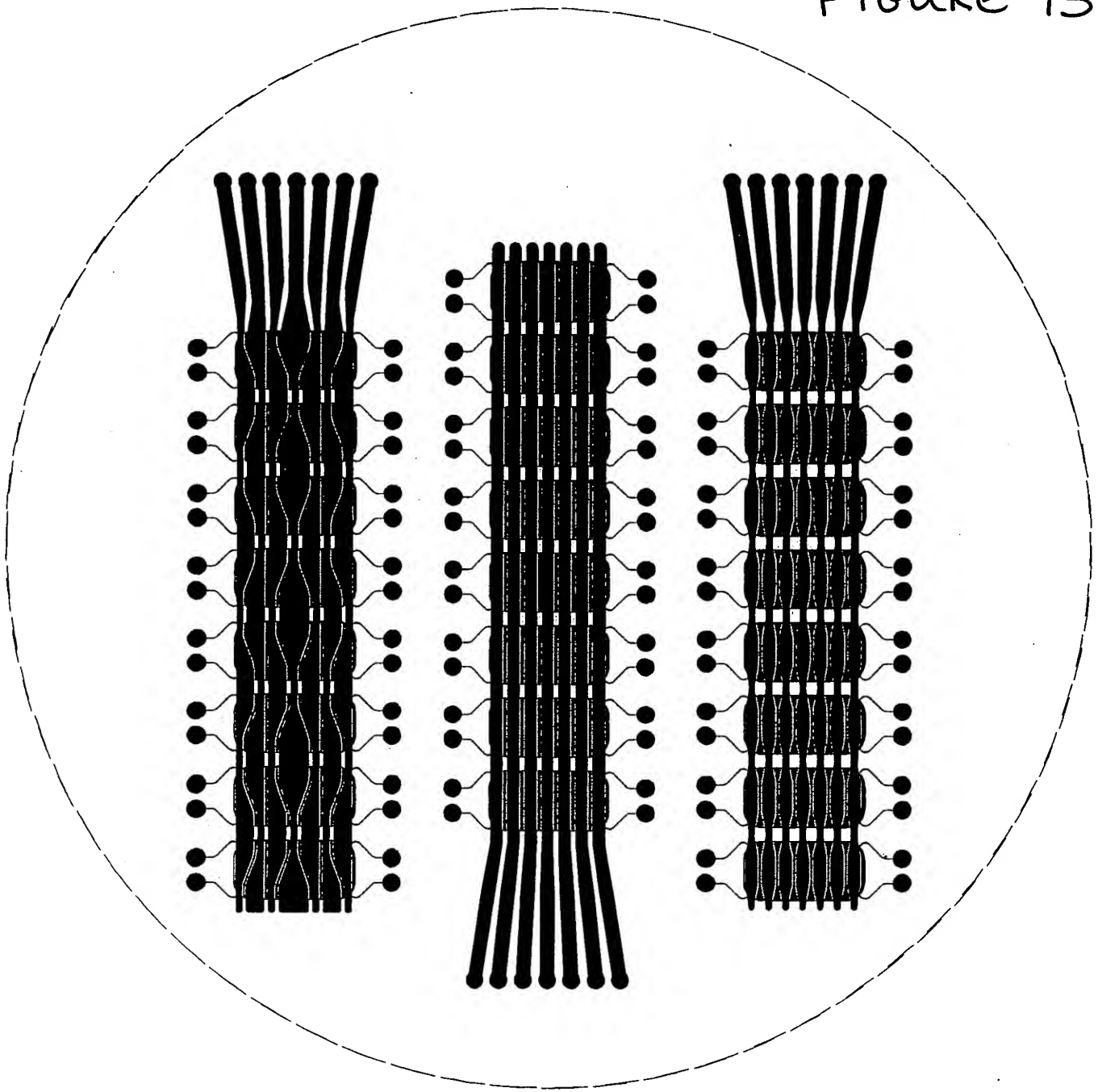
FIGURE 14



This is the mask for three different kinds of tubes. The left is the "wiggle tube" to drive flow transverse to the peristalsis direction. The middle is the standard straight tube, and the right are straight tubes with narrower regions near the edges of the wells. (The next slide shows the two masks overlayed)

The dark areas on the mask will result in raised structures (typ: 200-400μm) on a silicon wafer substrate to form the mold. After casting the elastomer and peeling it off, the dark areas will be cavities in the silicone elastomer.

FIGURE 15



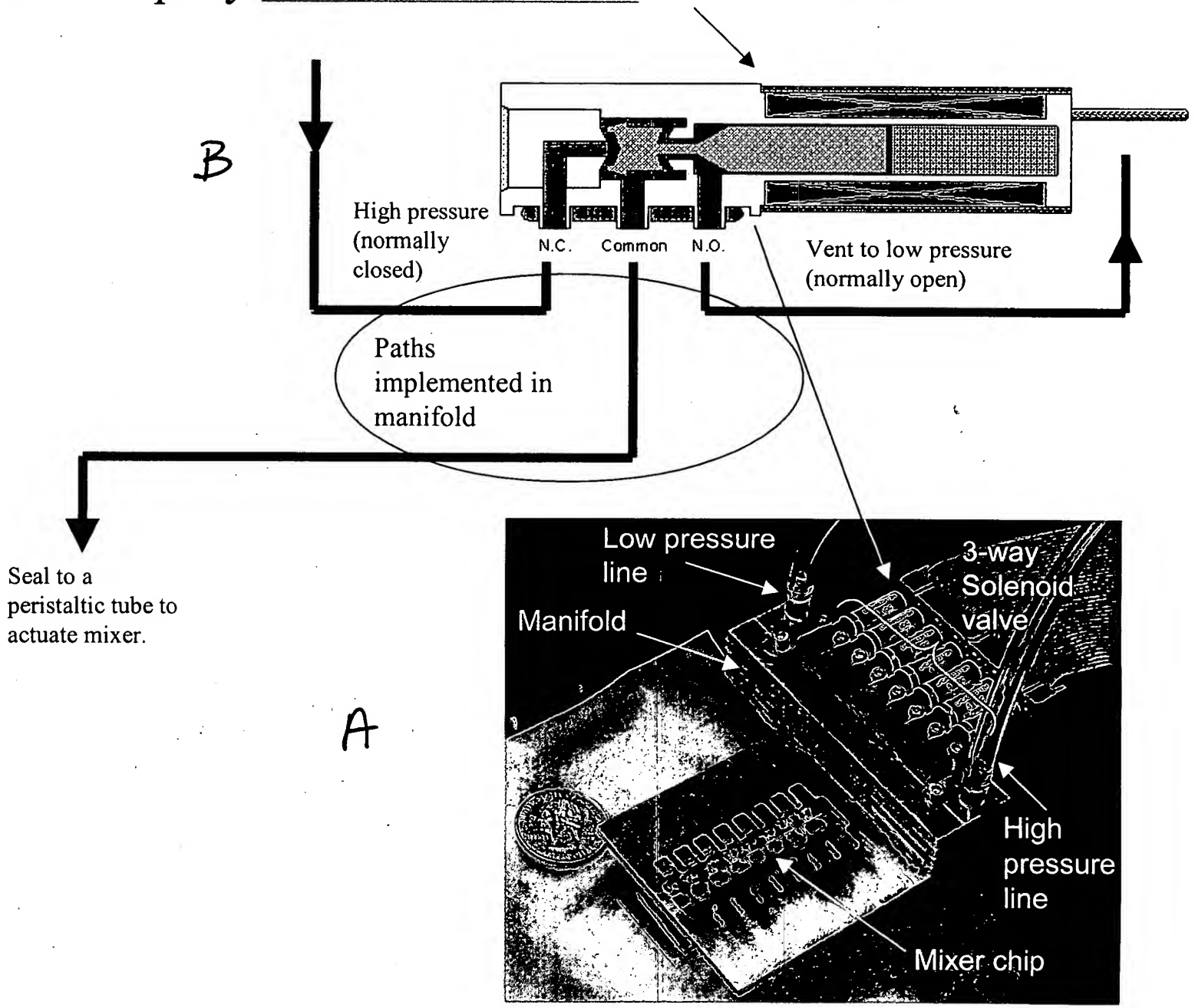
This shows the two masks overlayed.

A key part of the design is the scalability. Note that only seven macroscopic actuators (Lee company solenoid valves – see later slide). Are required to actuate 8 wells because each tube crosses over eight wells. By making it longer, scalability would improve. (7 valves actuate 16, or 32 wells) Current implementations are limited by the clean room processing tubes, and easy availability of 1x3 inch microscope slides substrates.

Minimizing the number of actuators is important to reduce overall system size and to keep to simplify the assembly of the macroscopic actuators.

The Lee Company www.theleeco.com LHDA valve

FIGURE 16



Exploded view of manifold, which mainly serves to reduce the pitch of the solenoid valves down to the pitch of the acutation ports.

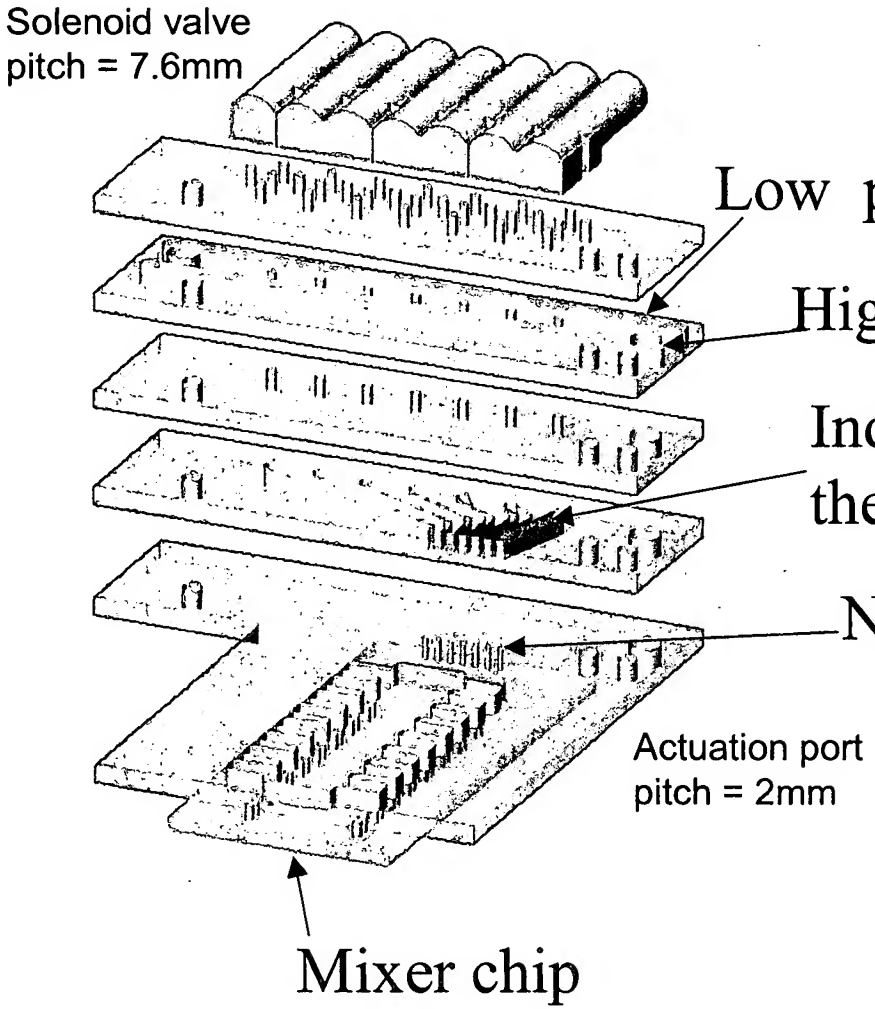
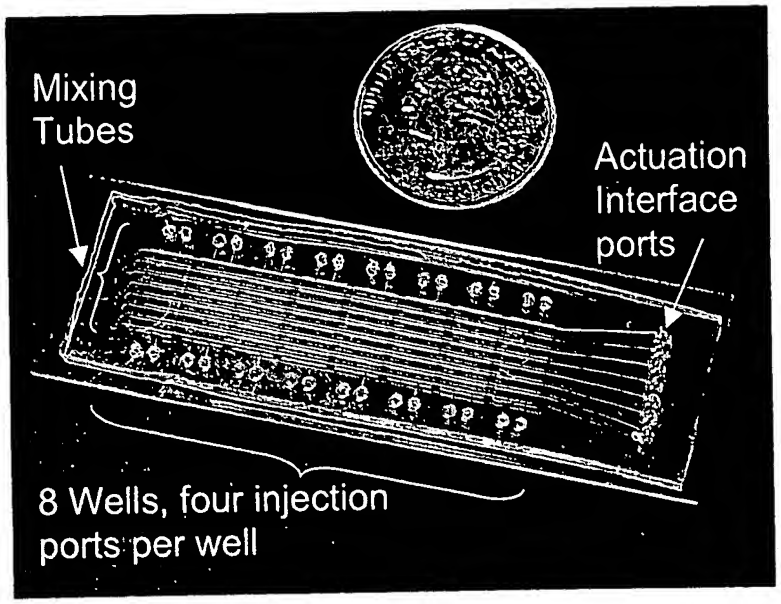
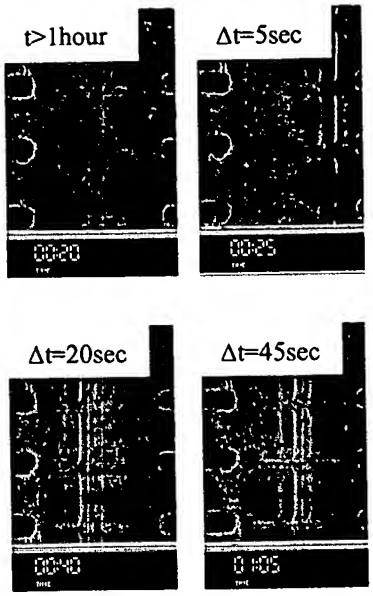


FIGURE 17

FIGURE 18

FIGURE 19





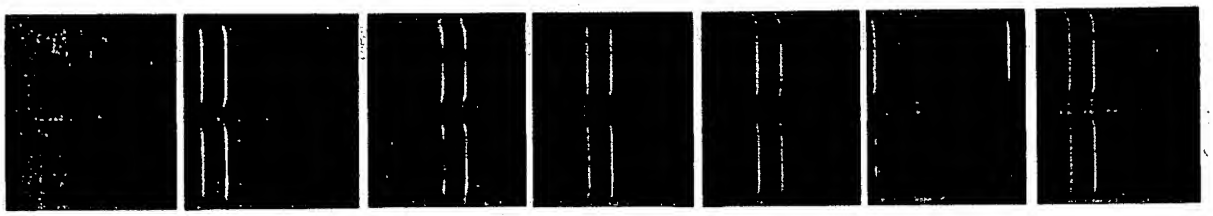
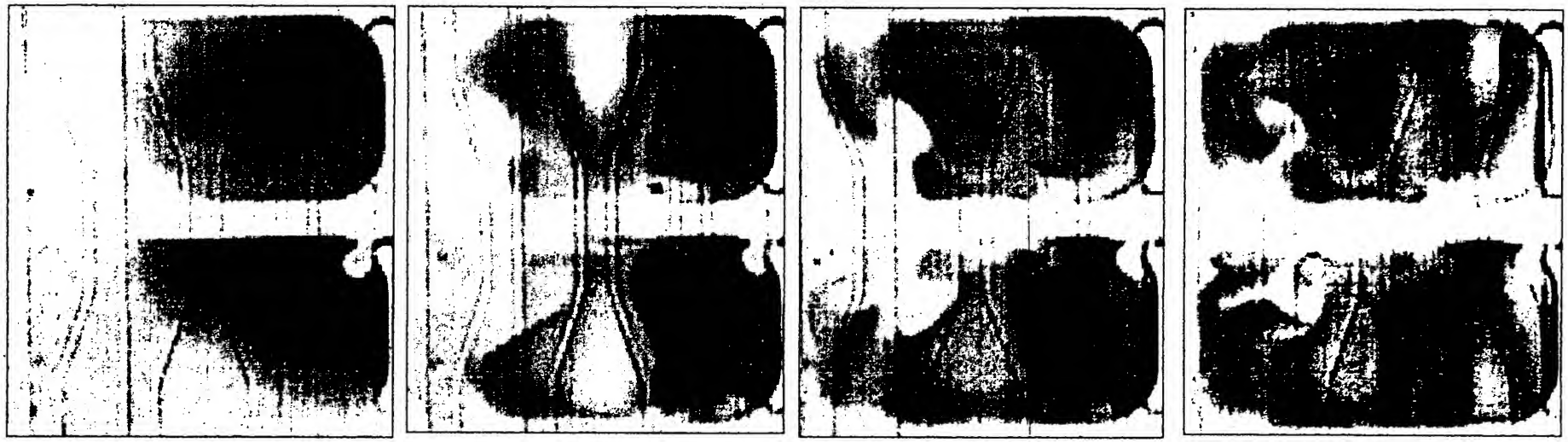


FIGURE 20

FIGURE 21



t~ 5min | Δt=1sec | Δt=2sec | Δt=3sec

Δt=4sec | Δt=5sec | Δt=6sec | Δt=10sec

Note, the light areas look light because the tubes are deflected and the dye is pushed away, allowing more white background to show through. 8psi, 100Hz.

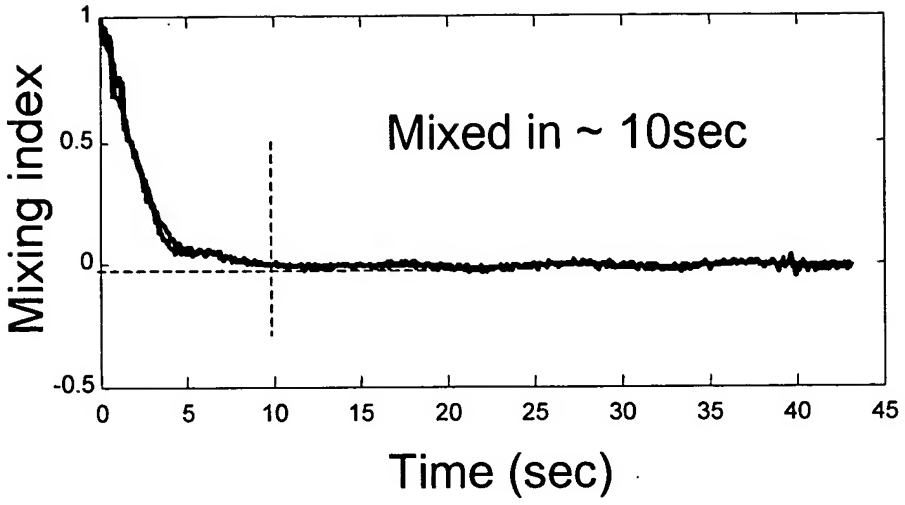
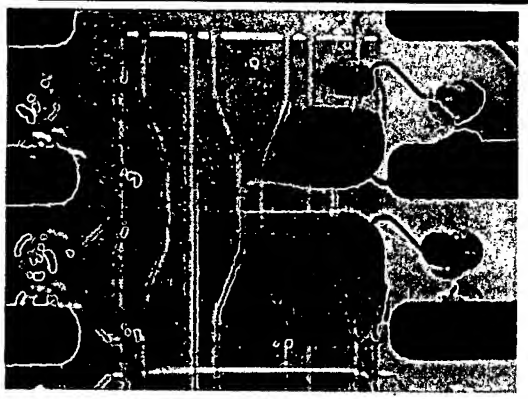

Mixing index
1
0.5
0
-0.5
0
5
10
15
20
25
30
35
40
45
Time (sec)
Mixed in ~ 10sec

FIGURE 22

FIGURE 23

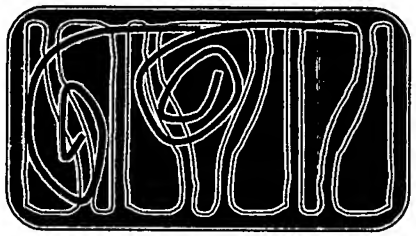
Mixing Results



Slow, 10Hz actuation rate, 8psi

Corn syrup

Water

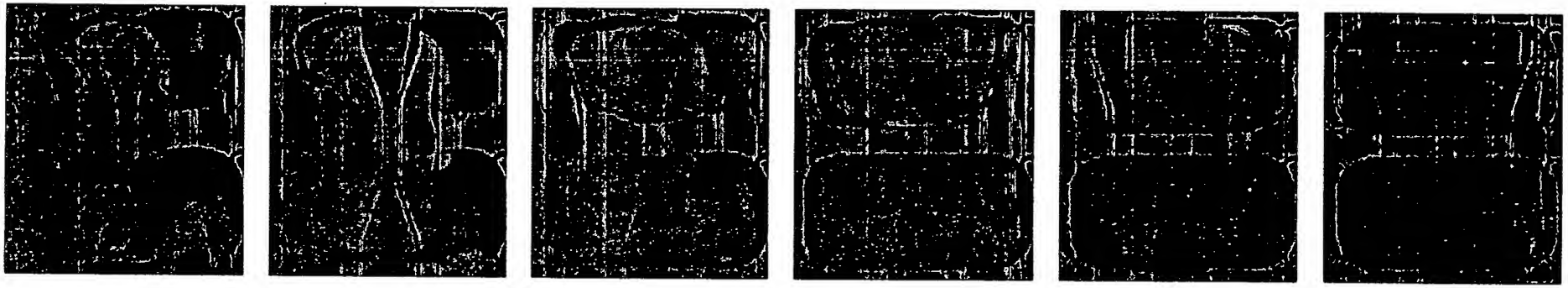


Upper/lower half symmetry broken, no more separated flow, but sometimes vortices don't mix.

Corn syrup

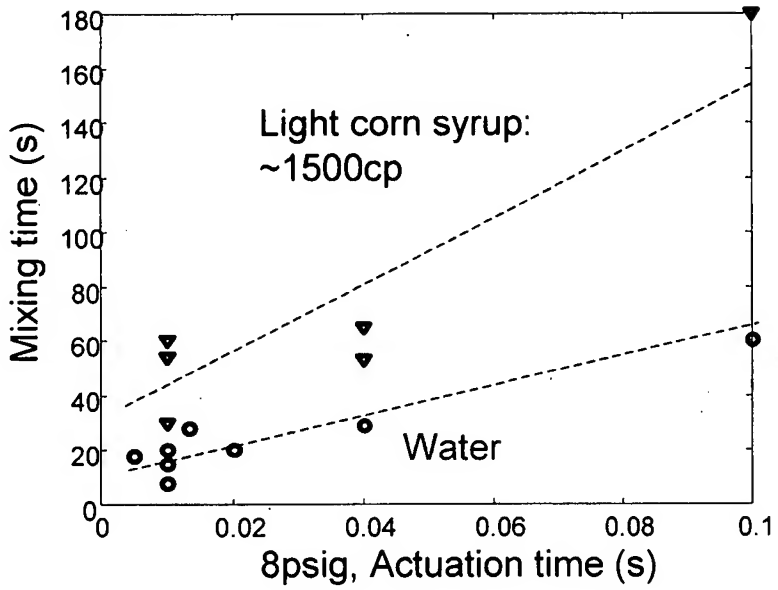
Fast, 100Hz actuation rate, 8psi

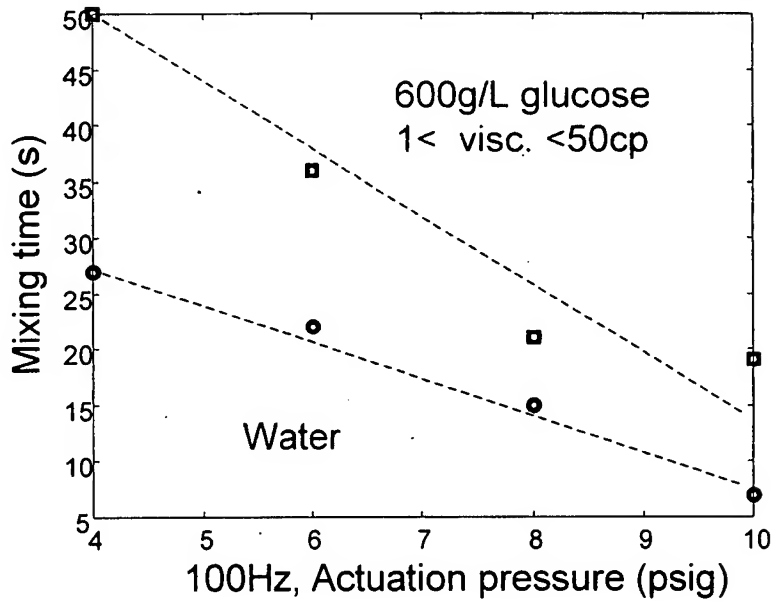
Water



Δt=1sec Δt=2sec Δt=4sec Δt=8sec Δt=16sec Δt=32sec

Mixing trends





A

B

FIGURE 24